THE VARIABLE APPEARANCE OF THE EARTH FROM SATELLITES

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ABSTRACT

The appearance of the Earth as seen from space changes continually. These changes in brightness and in color are produced by interactions between (1) geographical factors, such as coasts and mountains; (2) seasonal factors, such as the brightness changes due to the deposition and disappearance of snow; and (3) meteorological effects such as the cloud patterns indicative of the formation, development, and movement of tropical and extratropical disturbances.

The region of the spectrum in which the Earth is viewed influences its appearance. For example, to a satellite, clouds appear as high-energy sources in reflected short-wave, solar energy, but as cold, low-energy sources in emitted radiation.

All these effects are illustrated with pictures and measurements from TIROS satellites. A high resolution picture recovered from the Mercury project is also included.

1. PREFACE

This article is an outgrowth of Dr. Harry Wexler's renown in the scientific world. Because he was associated with scientists in many disciplines, he was asked to supply a chapter, dealing with earth-satellite observations, for an astronomy book about planetary atmospheres. He suggested that I write such a chapter. After an early draft had been written, the editors decided not to produce the proposed book after all. That early draft, although intended for an astronomy book, has been revised and shortened into the present article.

In a sense, articles about the appearance of the planet earth are continuations of Dr. Wexler's own forward-looking concepts on this subject [10, 11]. And so Dr. Wexler's influence continues.

2. INTRODUCTION

The earth, like a revolving kaleidoscope, exhibits a continuously changing appearance. Seasonal factors, geographic factors, and meteorological factors—these among others—act with subtle interplay to present a magnificently varying scene to the space observer. Consider, for example, the variations introduced by snow lying on the earth's surface. In middle latitudes, the presence of snow on the surface is mainly a *seasonal* effect. Yet the *geographical* influence of mountains prolongs the seasonal effect and in glaciers perpetuates the ice through all seasons. Moreover, the *meteorological* factors which deposit the snow in the first place are variable and may be more effective in one year than in another.

Many features of the earth as seen from the meteorological satellite, TIROS I, were presented by Fritz and Wexler [5.] But, when we consider the restless variability of the brightness patterns which the earth presents, it is evident that only a few of the interesting patterns observed could be described. Moreover, five additional TIROS satellites have already been launched by the National Aeronautics and Space Administration before May 1963; and these have contributed new information both from television pictures and from their radiation-measuring sensors.

To supplement the earlier discussion [5], this article will illustrate and discuss selected additional facets of the earth's continually changing appearance from space.

3. METEOROLOGICAL-GEOGRAPHICAL EFFECTS

When color pictures are available, large variations of the color and brightness of the cloudless earth are seen, ranging from the bluish horizon to the dark red surface in Africa. Such a color film was recovered from one of the NASA Mercury orbital flights [7].

But even black and white pictures show many terrain features. And superimposed on the variegated surface, are meteorological effects which are themselves in part produced by the character of the terrain. Coastal regions and mountains are particularly effective in their interactions with meteorological effects.

WEST COASTS OF CONTINENTS

Because of the variable magnitude of the large, oceanic anticyclones, the temperature of the cold surface-water and the character of the low-level atmospheric inversion near the west coasts of continents change from time to to time. This combination of circumstances—oceanic, geographic, and meteorological—sometimes produces widespread fog and stratus clouds. At other times

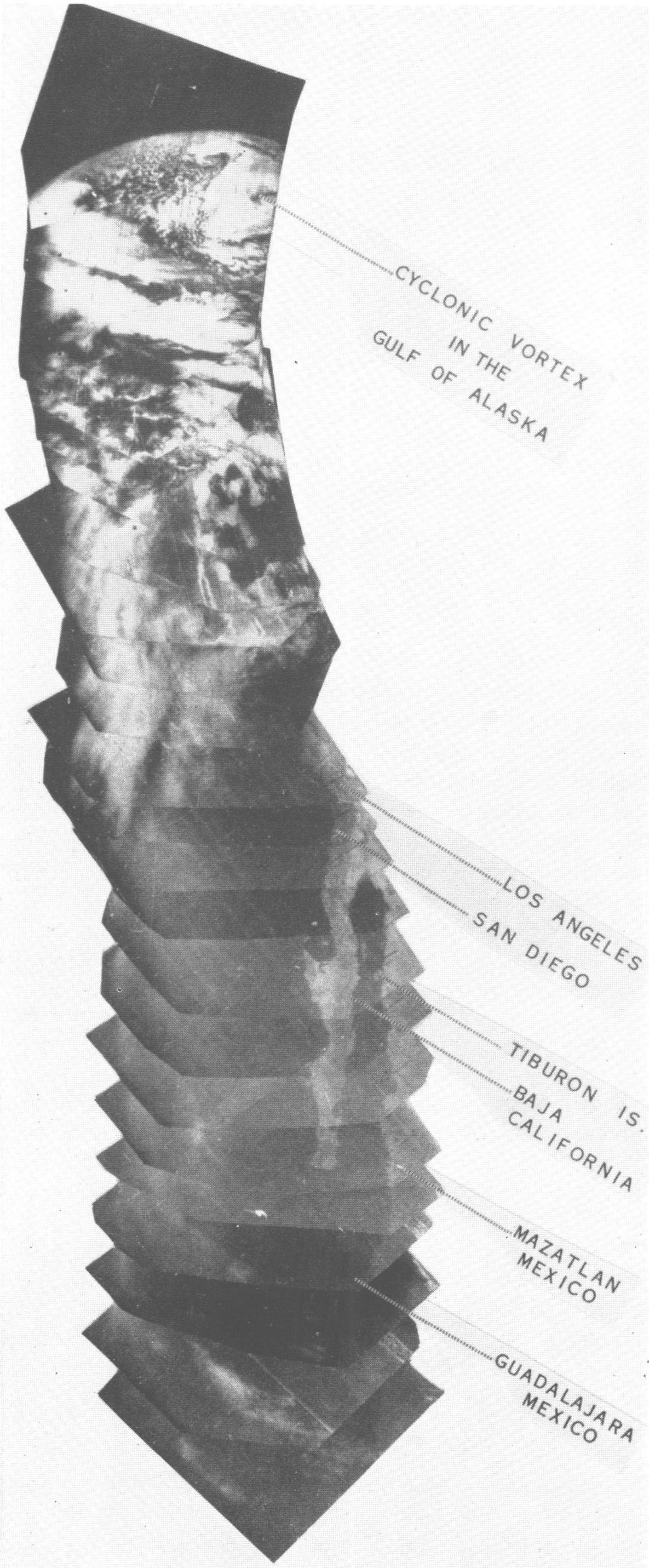

FIGURE 1.—A composite of pictures taken from the Gulf of Alaska to Mexico. The sharp outlines of the coastal features of Baja California indicate that the sky was cloudless there. TIROS I, orbital pass 6, April 1, 1960, 2200 GMT.

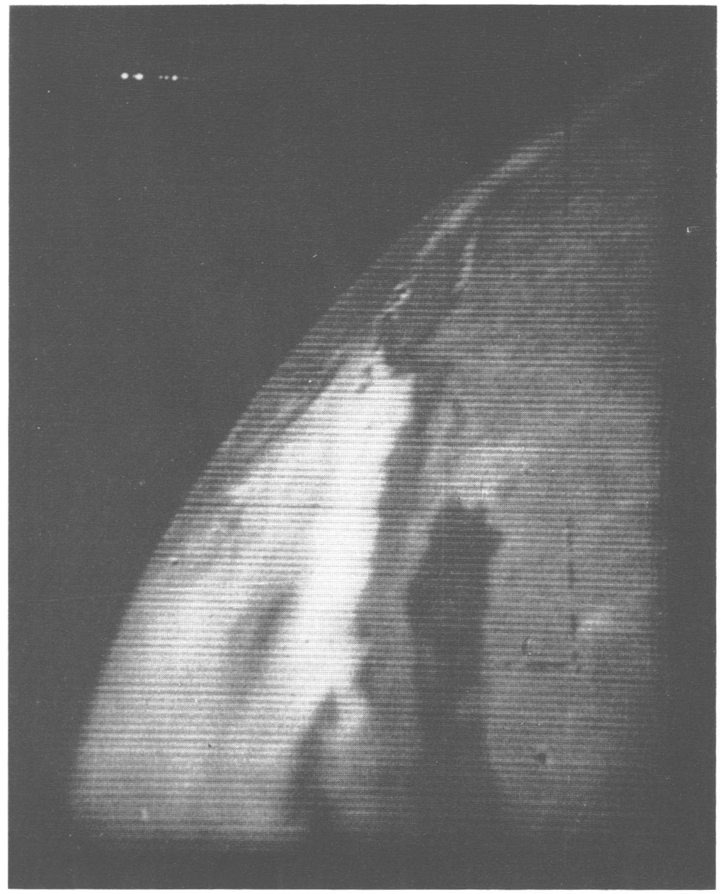

FIGURE 2.—A single frame showing stratiform clouds extending westward from the coast of Baja California and southern California. The Gulf of California appears to be cloudless. TIROS I, orbital pass 120, April 9, 1960, 1824 GMT.

cloudless skies may prevail, while seasonal effects may introduce unstable cloud forms.

The west coasts of North America, Africa, and South America display these effects in the TIROS satellite pictures on many occasions.

Cloudless Condition.—Figure 1 shows a composite made from frames taken on the day TIROS I was launched. The Gulf of California with its small islands, and the Baja California Peninsula with its characteristic bays, are common features in TIROS pictures for the contrast between bright land and dark water is quite good in this region. In figure 1, the coastal area along Baja California appears clear. Farther to the north, clouds are present over the ocean and still farther northward a mature vortex lies in the Gulf of Alaska [12].

Fog and Stratus Clouds.—By contrast with the cloudless conditions of figure 1, figure 2 shows a fairly widespread stratus cloud hugging the coast from the Bay of Sebastian Vizcaino in Baja California to Los Angeles and northward. The cloud extends hundreds of miles to sea, with some prominent holes evident in the cloud. Fog and stratus

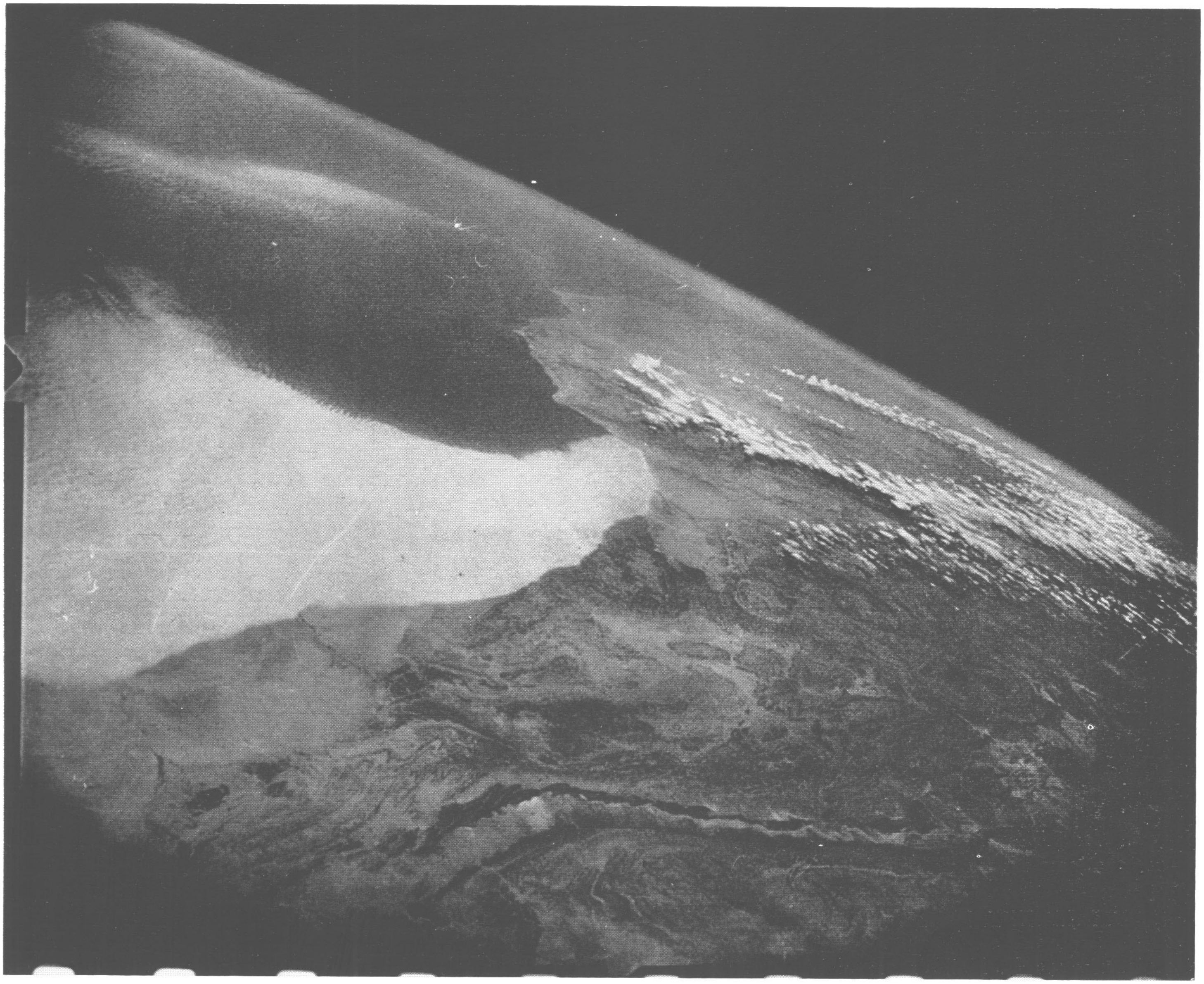

FIGURE 3.—A picture taken by Project Mercury camera on September 13, 1961, at about 1415 GMT. A stratiform cloud lies along the Atlantic coast of Morocco; the clouds become stratocumulus cloud away from the coast. Note the marked variations of brightness in the land features.

also appear in the TIROS pictures along the west coast of Africa and South America. But in a picture with higher resolution than the 2-mi. resolution of the TIROS wide-angle pictures much more detail can be seen. This is evident from figure 3 taken from the Project Mercury orbital flight on September 13, 1962. That satellite, orbiting at a height of about 90 n. mi. contained a 70 mm. color movie camera so that the resolution was much higher than the resolution in the TIROS system. Figure 3 is a black and white picture made from the recovered color film. A white, stratus or stratocumulus cloud lies along the Moroccan Atlantic coast. The Atlas Mountains appear partly covered with clouds, while various patches of darker and brighter terrain mark the mountainous area. The dark ribbon-like feature in the right foreground is associated with ridges and valleys which lie just south of the Dra River.

Unstable Conditions.—When the atmospheric conditions change substantially, clouds associated with unstable thermal stratification may appear. Such clouds are cumuliform in character and may consist of fairly large conglomerations of cloud elements. Figure 4 shows the Baja California area in summer during such a situation. The water areas are cloudless, but the land areas, partly because of intense heating during the day, are covered with fairly large cloud masses which in some cases are more than 50 mi. wide. The north-south chain of cloud elements along the peninsula lies along the higher mountain elevations.

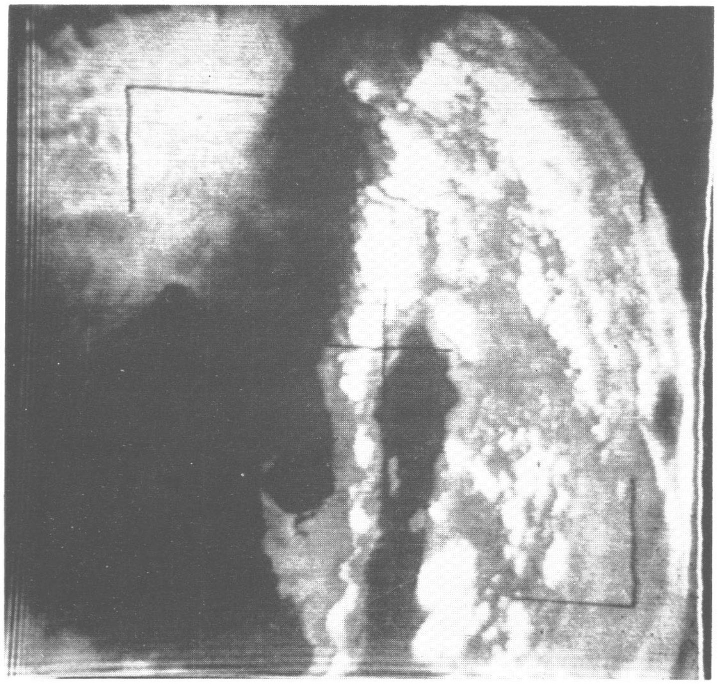

FIGURE 4.—A picture of Baja California showing bright patches of cumuliform clouds. The coastal areas appear cloudless. TIROS III, orbital pass 581, August 21, 1961, 2202 GMT.

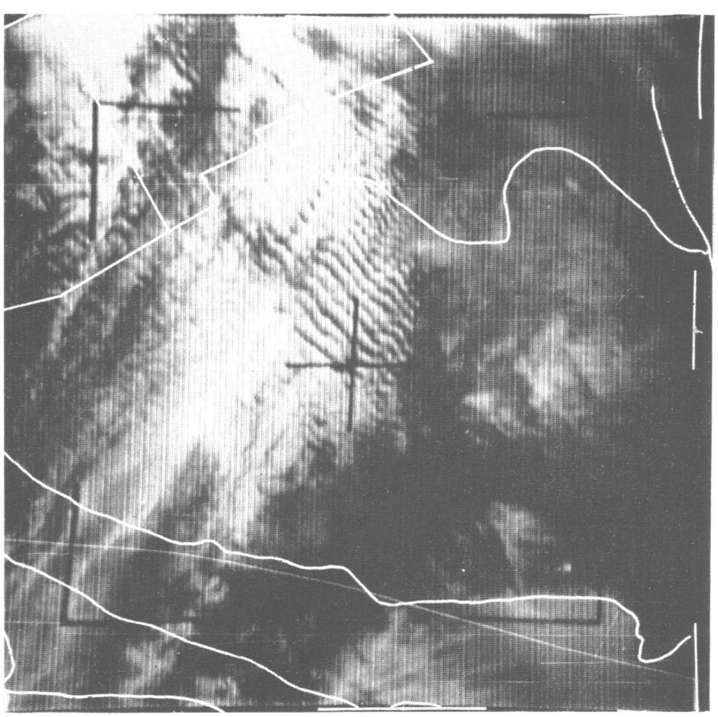

FIGURE 5.—Wave-cloud patterns produced by the Sierra Madre Occidental Mountains. The outlines of Mexico, Texas, New Mexico, and Arizona have been superimposed on the pictures. TIROS VI, orbital pass 851, Nov. 15, 1962, 1710 GMT.

MOUNTAINS

Wave Clouds over Mountains.—The irregular terrain in mountains introduces many small-scale local effects; and many TIROS pictures show these irregular effects. But when the wind flows at right angles across an extended mountain range, during times of stable vertical temperature distribution and suitable wind structure, a wave perturbation will form in the lee of the mountains. If the moisture is adequate, this wave is evident in the cloud pattern. An outstanding example of such a cloud pattern in the lee of the Andes Mountains was analyzed by Döös [2]. Figure 5 shows another striking wave cloud pattern which was formed by the flow of air over the Sierra Madre Occidental Mountains in Mexico.

It is interesting to note that clear air turbulence was reported near El Paso near the time of this picture. An interesting subject for further study is the question as to whether clear air turbulence in such mountainous regions is caused by the presence of a jet stream in the area, or by the high-altitude influence of terrain effects which produce wave clouds and other cloud patterns, or the interaction of both jet and terrain influences. If the terrain influence is important, as it seems to be [1], then cloud patterns produced by the terrain may offer clues to areas in which clear air turbulence may be suspected.

4. SEASONAL CHANGES

The earth's surface changes with the seasons in several ways. In cultivated areas, such as in the center of the United States, the surface changes from the spring through the summer season and into autumn as agricultural pursuits change the plowed terrain to crop-covered ground and then clear it again. But, this change does not introduce any large variations in brightness and is mainly undetectable in the TIROS satellite system.

SNOW

However, there is one seasonal change, namely the one due to the deposition of snow or ice on the earth's surface, which does change the brightness of the surface drastically and this type of change is easily portrayed in the view from space. Along the Atlantic Coast of the Middle Atlantic States the contrast between land and ocean is usually small, so that although the coast is sometimes discernible with the TIROS system resolution, it often cannot be detected at all.

There are, however, two conditions under which the coast becomes quite discernible. One occurs when the ocean appears bright because of specular reflection [5]. The other occurs when the land near the coast becomes snow covered. On cloudless days, the snow-covered land stands out in marked contrast to the dark ocean water.

Snow also has a marked seasonal effect on the brightness of mountain areas. Figure 6 shows a picture taken in April of snow on the Cascade Range and in the Rocky

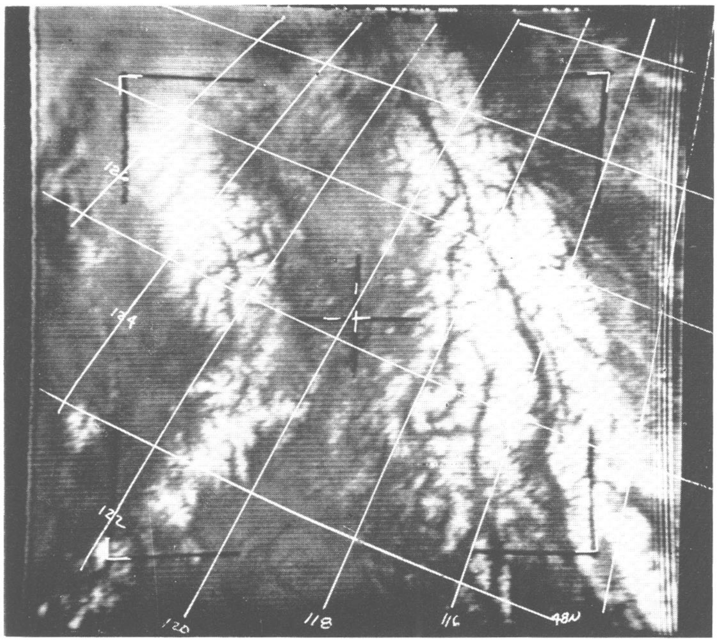

Figure 6.—Snow on the Cascade Mountains and on the Rocky Mountains. Mt. Olympus is snow covered at about 48°N., 123.5°W. The Columbia River in Canada, and many other readily identifiable rivers and valleys, appear dark in the picture. A latitude-longitude grid has been superimposed. TIROS IV, pass 895, April 11, 1962, 2100 GMT.

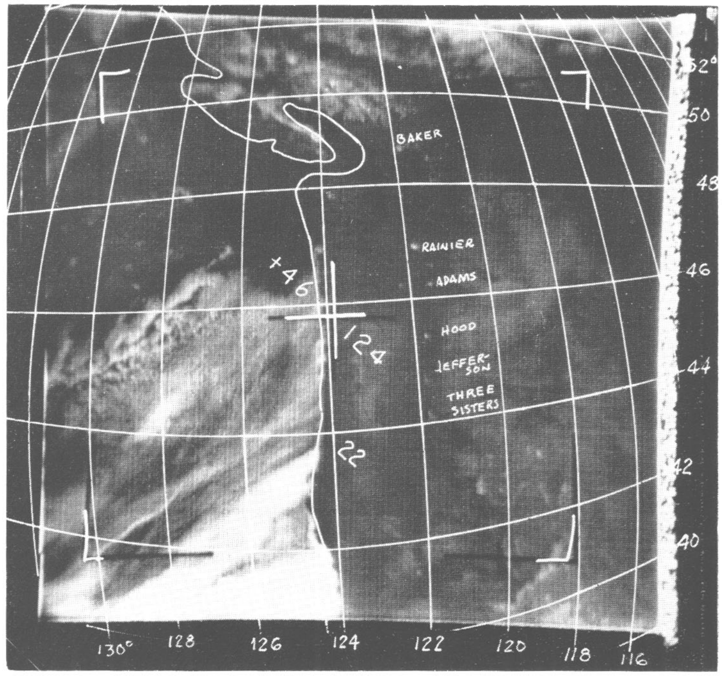

Figure 7.—The western United States and southern Canada in summer. Several of the higher mountain peaks appear as white dots and have been labeled. Mt. Olympus (see also fig. 6) appears as a small white dot. Note the brighter, snow-free land features in the vicinity of 46°N., 120°W. TIROS I, pass 951, August 24, 1962, 1855 GMT. A latitude-longitude grid and the outline of the west coast have been superimposed on this picture.

Mountains. The pattern on the Rocky Mountains was repeated on several days [3], and emphasizes the darker river valleys. By contrast, a part of the same area photographed during August is shown in figure 7. Especially between latitudes 48°N. and 50°N., most of the snow has disappeared and the area appears of course much darker. It is interesting to note the series of white dots oriented north-south in the Cascade Range associated with individual high peaks. Mt. Baker, Mt. Rainier, Mt. Hood, and others can be readily identified.

Ice appears on some rivers in winter and disappears in summer. This changes the appearance of the river and in winter and spring various types of ice are characteristically portrayed in satellite pictures [9].

5. METEOROLOGICAL EFFECTS

Of course the varying meteorological cloud systems introduce a variation in the appearance of the earth independent of any mountain or other surface geographic features. Over large ocean areas, for example, cloud systems form, develop, and dissipate while they move across the surface. And so the appearance of the earth from space varies because of the movement of the cloud system relative to the surface, and because of the changes which the developing or decaying cloud systems undergo continually.

Innumerable examples of cloud systems, developing and moving across oceans, have been photographed by the

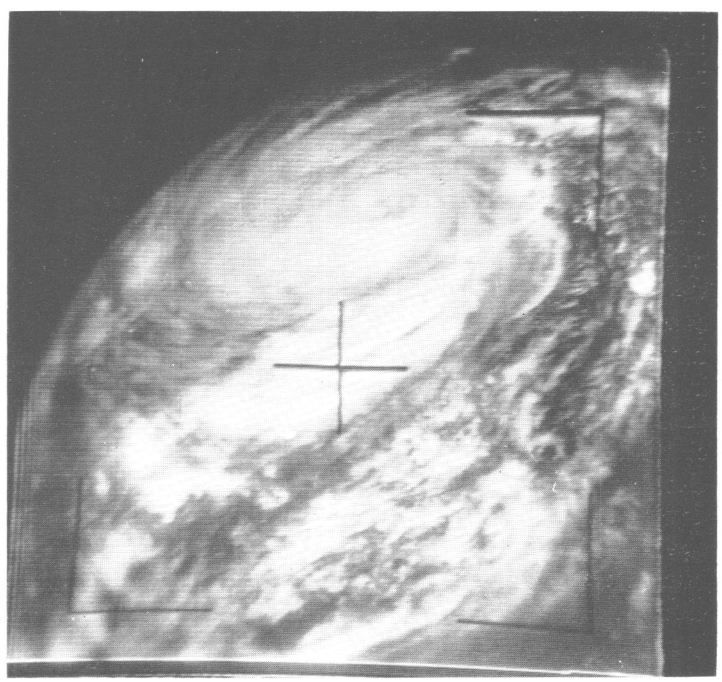

Figure 8.—A picture of typhoon Wanda taken near 20°N., 123°E. TIROS V, pass 1034, August 30, 1962, 0031 GMT.

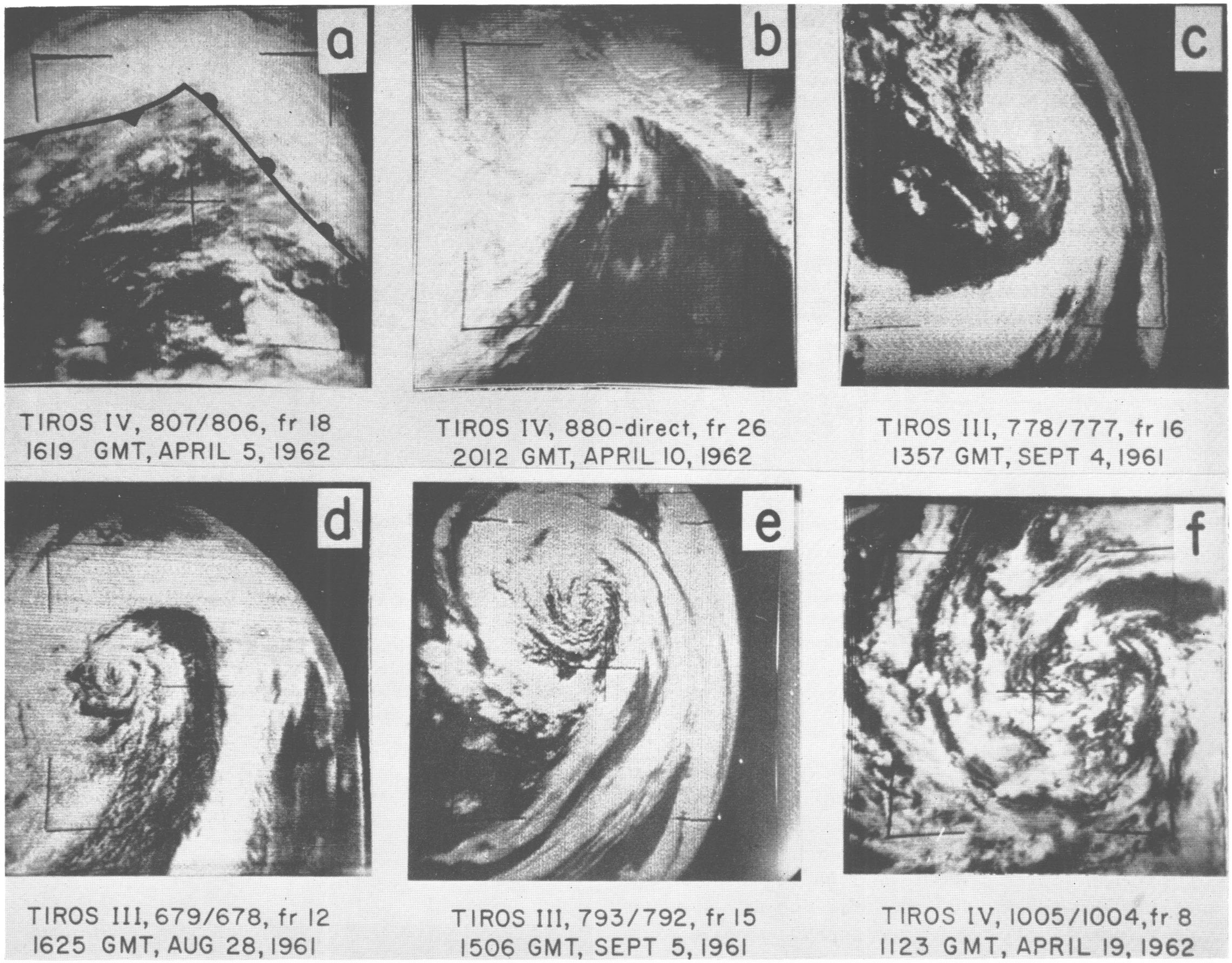

FIGURE 9.—Cloud pictures of several cyclones in various stages of development from the open wave stage (a) to the occluded, decaying stage (f). The pictures in (c) and (e) are cloud patterns of the same storm about 25 hr. apart in time.

TIROS satellites. For example hurricane Anna (1961) was traced from its early, undeveloped stages, across the tropical Atlantic until it became a hurricane in the Caribbean Sea [4]. But many other typhoons and hurricanes have also been tracked. Figure 8 shows typhoon Wanda, in a well developed stage. The dark spot associated with the eye is clearly seen. And the large spiral "arms" and cirrus striations are also easily discernible. The cirrus cloud shield, sometimes seen as a spiral array in a well developed typhoon, is often indicative of the anticyclonic outflow at the top of the storm. Since typhoons and hurricanes generally begin in rather unorganized-looking cloud masses in the easterly wind zones of the Tropics, it is evident that the development which led to the highly organized cloud array on figure 8 must present a continuously changing scene when viewed from space.

In the same way, the movement and development of extratropical cyclones continuously alter the "face" of the earth. Figure 9 is an array of cloud patterns which were produced by several different storms each in a different stage of development. Figure 9a and 9b show the cloud patterns associated with an open wave, with warm air lying south of the cloud and cold air to the north. In figure 9c the cyclone has begun its occlusion process; the cold, sinking, dry air (dark in the pictures) is invading the cloudy, moist air. At such a stage, the upper-air isotherms and isobars are often out of phase. Figure 9d represents a very deep occluded system 24 to 30 hr. after occlusion had begun; the central pressure was 978 mb. Finally figures 9e and 9f represent older occluded cyclones; and especially figure 9f shows that the organization in the center of the cyclone has become less marked than in the earlier stages. During this stage, the upper-air isotherms and isobars can be expected to be nearly parallel.

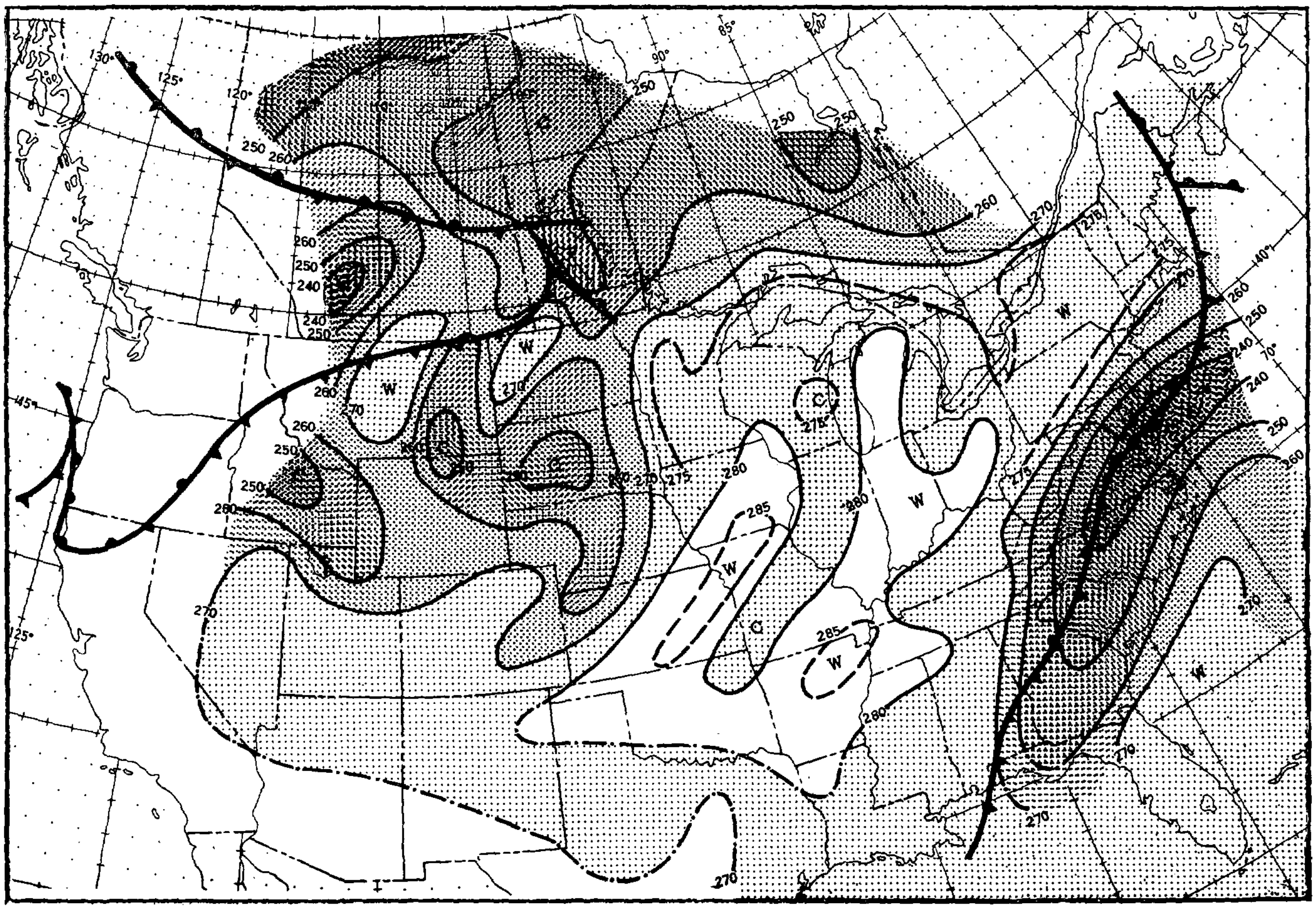

Figure 10.—The distribution of outgoing energy from the earth plus atmosphere in the 8–12 micron water vapor window as measured by TIROS II, near noon November 23, 1960. The energy is expressed in degrees Kelvin of equivalent black body temperatures.

Thus, it is evident that in data-sparse regions such as the Pacific Ocean area, the areas south of Australia, east and west of South America, and in many other regions, pictures such as those in figure 9 supply important data not only about the location of a storm, but also about its state of development.

6. SPECTRAL VARIATIONS

The appearance of the earth depends also on the wavelength of the "light" in which it is viewed. The TIROS pictures were viewed in light at wavelengths between about 0.5 and 0.7 microns. However, it is possible to view the earth in infrared radiation, and TIROS II, III, and IV carried instruments to measure the infrared emission from the earth. Whereas in visible light, clouds appear bright because they reflect the short-wave solar energy strongly, in far infrared wavelengths, clouds, for the most part, emit less energy than cloudless regions. This occurs because clouds are usually colder than the underlying surrounding surface. An example of this is seen in figure 10 which shows the radiation data [6] in the water-vapor window at wavelengths between 8 and 12 microns taken from TIROS II near noon on November 23, 1960, with a resolution of about 20 mi. The colder, generally cloudy areas have been shaded dark because they emit less energy than the clear areas. A cold front along the east coast of the United States was associated with a multi-layered cloud system. A cirrostratus layer was located between 25,000 and 32,000 ft., and an altostratus cloud lay below that with a top of about 14,000 ft. Thus these clouds were quite cold by comparison with the warmer sunlit ground in the Midwest. From the distribution of the measured radiation in figure 10, it was possible to estimate the temperatures of the cloud "tops"; and from the estimated temperature, estimates of the height of the cloud top could be made by the use of radiosonde data.

In the infrared, marked diurnal variations also occur, especially, in cloudless, dry, land areas where the ground may cool markedly during the night and heat up appreciably during the daytime. Thus at 0700 CST on November 23, 1960, five hours before the observations in figure 10 were made, the radiative "effective" temperature as seen by TIROS II over Wisconsin was 20°C. colder than it was at noon.

7. CONCLUSION

Thus the appearance of the earth varies as a result of many factors and much of this variation can be seen from TIROS satellites. But not all factors were considered fully. The variation from place to place due to color variations of the terrain is quite marked. This is evident in the Project Mercury film. The appearance in visible colors and also in the near infrared changes appreciably with vegetation cover which in turn varies seasonally and geographically.

Finally the earth's appearance varies both with space and time scales. As later models of satellites become available, such as the Nimbus and Aeros systems [8], variations on smaller time scales will be discernible in visible light, and higher spatial resolution will be available in the infrared observations.

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